New Methods to Study Seismic Migration

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Seismic migration, a process in which a seismic wave field recorded on the Earth's surface is back-projected to obtain an image of the reflectivity of the Earth's subsurface, is a crucial step in processing seismic exploration data Unfortunately, conventional seismic migration methods used by the petroleum industry are computationally expensive, of limited reliability, and based on assumptions that limit the quality of the images. To improve the seismic migration process, we are focusing on two activities: improving the standard Kirchhoff-based approach to seismic migration and developing wave-equation-based migration (dual-domain, space-wave number) methods. We are collaborating with industry in both cases.

In the Kirchhoff migration project, we are investigating new wave-front construction techniques in which we use reasonable estimates of the ray density to characterize the wave front. We are also investigating a wave-front construction approach in which the wave front is extrapolated in a more physically reliable and numerically stable manner. This approach provides more reliable travel times and uses less computing time than the conventional wave-front construction approach, in which the wave front is extrapolated in constant time intervals.

In the wave-equation migration project, we developed improved methods for migrating, based on solutions of the one-way wave equation. Our results have produced better images of petroleum fields than can be obtained using conventional dual-domain techniques. We are continuing to test these methods in the field.

Advances in Seismic Imaging and Modeling for the Petroleum Industry

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Three-dimensional seismic reflection methods are an excellent tool for oil and gas exploration, except for the massive amounts of data that can be generated. We have developed new seismic imaging methods that reduce computing requirements substantially with little or no degradation of the final image. This project is discussed in detail in the Research Highlights section.

Seismic Stimulation for Enhanced Production of Oil Reservoirs

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Approximately 60% of domestic oil resources remain unproduced, partially due to the limitations of enhanced oil recovery methods such as water flooding. Because historical data on seismic stimulation are inconclusive, we are performing additional laboratory and field tests to quantify the conditions and physical mechanisms under which seismic stimulation can increase oil recovery. Our major objectives are to determine the optimum wave-field parameters for effective treatment over a wide range of field conditions and to obtain a fundamental scientific understanding of the relative importance of the physical mechanisms governing the stimulation phenomenon.

To quantify the effects of dynamic stress stimulation on multiphase fluid flow in porous media, we are conducting laboratory experiments at a unique new Los Alamos core-flow facility. We are also monitoring field tests of existing down-hole seismic stimulation sources that are being developed commercially. These field experiments are being guided by the results of our laboratory work. We tested simultaneous two-phase fluid flow through a sandstone sample at several flow-rate ratios. We found that low-frequency (10–100 Hz) stress cycling decreases the fluid pressure drop across the core during steady-state flow of decane and brine. The magnitude of the decrease in pressure drop depended on the input stimulation amplitude and frequency. Lower frequency and higher amplitude produced the largest pressure decreases.

When 10-weight oil was used instead of decane, the effect of stimulation was reversed and the pressure drop increased during stress cycling. To further investigate this phenomenon, several experiments were performed. Instead of flowing two fluids simultaneously, non-steady-state displacement was used to simulate enhanced oil recovery (EOR) flooding procedures. During drainage and imbibition runs on sandstone cores, automated, real-time measurements of changes in oil and water production were obtained using an oil/water separation column. Our data indicate that mechanical stimulation may temporarily change the wettability of the rock, which results in the nonwetting fluid phase becoming trapped in the pore space, thereby releasing previously trapped wetting-phase liquid. The implication is that stimulation may be more effective at increasing production in reservoirs that are at least partially oil-wet.

We also monitored production and seismic stimulation sources in two separate oil fields, using two different seismic sources. Initial reports indicate that in both cases, oil production increased. During one field test at Lost Hills, California, seismic stimulation caused an increase in oil production of approximately 20%. This is similar to increases observed previously in the same field that were caused by the magnitude 7.1 Hector Mine earthquake.

Advanced Reservoir Management (ARM) Project

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As the major oil companies continue to move production operations abroad, independent oil producers have, for the most part, taken over domestic production. Since these independents have fewer resources available to them, the ARM project is developing new technologies to help them manage the domestic reservoirs. ARM, an industry/DOE cost-shared program initiated in 1995, is part of the Advanced Computational Technology Initiative at the Laboratory.

We are working on two projects as part of this initiative. For the first, we generated a detailed model of the distribution of heterogeneity in a reservoir in Carpinteria Field, California. We combined all of the available geologic data, including log and core data to generate distributions of porosity, shale volume fraction, and permeability. We used a 3-D geologic model, developed earlier in the project, as a structural basis for the geostastical characterization study, which included a study of the uncertainty associated with the property distributions. These detailed reservoir rock-property distributions and associated uncertainty measurements will help the current field operators plan future pumping strategies, giving them clear understanding of the potential for uncertainty in petroleum production rates.

For Big Sand Draw Field, Wyoming, we developed a numerical flow-simulation model and conducted flow simulations to study the effect of different rock properties on the overall production behavior. Our results indicate that the predicted porosity distribution has the most significant effect on the water production behavior. This will help reservoir managers anticipate problems associated with potential water in the reservoir from properties that are easily measured in new wells.

Well Perforation Dynamics

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As part of the Advanced Computational Technology Initiative, we are participating in a national project to improve the efficiency of the well completion process. A broad spectrum of the industry is providing their expertise, sharing their data, and performing experiments in support of this project. Los Alamos is the lead for modeling and analyses of experimental data. Other participants include LLNL and SNL; Haliburton, Marathon, Mobil, Schlumberger, and Shell from industry; and Colorado School of Mines and Penn State University.

The purpose of our project is to gain a better understanding of the physics and phenomenology involved in the well-completion process so that we can model the effects of perforation on rock damage and permeability reduction. We anticipate that this work will ultimately reduce the cost of now highly inefficient well completion treatments, a significant portion of which can be attributed to the effects of perforation. Using a variety of techniques developed at Los Alamos and SNL, we are modeling (1) perforation induced damage and cleanup and (2) particulate flow.

Focusing on perforation induced damage at the mesoscale (grain resolving), we model dynamic grain fragmentation by explicitly treating grain interactions with two particle-based methods: the smooth particle hydrodynamics (SPH) method and the discrete element method (DEM). Each grain is modeled using clusters of SPH or DEM particles to provide realistic representation of the grain and pore structure as obtained from x-ray synchrotron tomography and scanning electron microscope images. The modeling accommodates the influence of pore fluid, grain cementation, and clay content. (Dynamic grain fragmentation was studied experimentally.) It appears that this SPH/DEM modeling approach, in concert with definitive experiments, offers a unique way to better understand the physics of formation damage that results from perforation-completion treatments and to provide calibration for macrocontinuum-damage modeling. Our progress in developing statistical methods to correlate experiments with mesoscale modeling has proceeded to a point at which we can soon address upscaling from mesoscale to macroscale.

Stochastic Reservoir Simulation

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Our objective is to develop partial differential equations for the moments of single- and two-phase flows in heterogeneous oil/gas reservoirs, as an alternative to the commonly used Monte Carlo simulation approach. The workable moment equations have some important benefits over the Monte Carlo approach. First, there are a small number of equations to be solved: one equation for the mean, and one each for a small number of variances and co-variances. Second, the coefficients of the equations, as averaged quantities, are smooth; consequently, these equations can be solved on a relatively coarse grid. Third, the moment equations are available in analytic form, even though they are solved numerically in applications; this holds the potential for increased physical understanding of the mechanisms of uncertainty.

During the past two years, we developed moment equations for steady-state and transient single-phase flow in bounded domains of nonstationary media. The results from these models are the first two moments of flow quantities. The first moment (mean) can be used to estimate the field of the flow quantity of interest, and the second moment (standard deviation) measures the associated uncertainty (error). These two moments can be used to construct confidence intervals for the flow quantities. These flow models may be applied to both groundwater and gas reservoirs, and they have been partially validated using Monte Carlo simulations.

We also developed and solved the moment equations for steady-state and transient unsaturated flow in the vadose zone. In unsaturated media, water and air coexist in the pore systems. Unsaturated flow is treated as a special case of two-phase flow. We found that the boundary conditions, especially the water table boundary, have a significant impact on the stochastic behaviors of unsaturated flow in random porous media. For a true two-phase case of water displacing oil, we developed moment equations under both simplified and more realistic boundary conditions. We have compared the stochastic model of two-phase flow with Monte Carlo simulations and have found a very good agreement.

Testing Advanced Computational Tools for 3-D Seismic Analysis Using the Society of Exploration Geophysicists/ European Association of Geoscientists and Engineers (SEG/EAEG) Model Data Set

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In collaboration with the Institute Français du Petrole (IFP) and other U.S. national laboratories we created two synthetic difficult-to-image geological models (a salt and an overthrust model) and calculated synthetic seismic reflection data from each. We also developed a new technique we call “common azimuth imaging,” which speeds up the imaging of marine seismic reflection data and is comparable in speed to the widely used Kirchhoff migration method. Using this technique, we are able to image fine-scale and subtle features of potential exploration targets; it has also been effective using data from both the SEG/EAGE and field data sets. One data-acquisition geometry simulated a typical marine survey, with towed source and receiver array. The second simulated a survey that used a few vertical arrays of receivers (vertical receiver cables) and sources spread across much of the horizontal extent of the model. Although the quality of the imaging of this data has so far has been relatively poor, we have continued to be funded so that we can process all the data sets and better understand the reasons for poor imaging.

Using Coupled Models to Improve Seismic Exploration Strategies

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Seismic exploration surveys, which use explosive charges to study the presence, depth, and configurations of underground formations, have remained relatively unchanged over the years. They are often expensive, and the quality of data is sometimes uncertain. To reduce costs and improve results, field strategies for these complex surveys must be improved. We recently entered into an agreement with an external service company to apply our computational tools to improve seismic exploration surveys.

We are focusing on the influence of charge geometry and near-source material properties on the amplitude and directionality of the induced seismic energy. We use a unique numerical method in which we couple the Solid Mechanics Code, which models the near-source energy deposition imparted to the rock media by the explosive charges, with the Anelastic Finite Difference Code, which models the far-field seismic wave propagation of that energy. The sponsor’s parallel field experiments have validated our findings that geometric coupling between different source configurations will have a major effect on the differences in seismic efficiency and energy directionality. As a consequence, our sponsor is developing new design and execution strategies that will hopefully result in lower-cost, more-reliable exploratory surveys. We gained insights on charge type, size and shape; depth-of-burial; and tamping in rock similar to the field-test sight from the modeling and field tests.

We plan to use other Los Alamos hydrocodes and anelastic wave propagation codes to extend this work and model additional tamping materials, rock types, and explosives. We are continuing to define efficient and cost-effective borehole explosive configurations for seismic exploration. These include investigating the effects of propellants in place of high explosives and of variations in the physical properties of the rock surrounding the borehole.